Power Distribution Investigation of a Diffused Cellular Indoor Visible Light Communication System

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***Abstract-* This paper presents a three dimensions (3D) model of optical power distribution in a diffused cellular indoor visible light communication (VLC) system. To achieve an ideal system which has a maximum coverage area with a minimum power consumption, both hexagon geometric structure and holographic light shaping diffuser (LSD) are employed. We analysed the mathematical models for both square and hexagonal structures with and without using LSD. In addition, the practical system consisting of a (Luxeon Star/O) royal blue LED as a transmitter is used to verify and evaluate the system performance. The system operates at a date rate of 5 Mb/s using the on-off keying non-return-to-zero (OOK-NRZ) modulation format. The simulation results show that using hexagon geometry and a 30^o holographic LSD diffuser, the received optical power distribution becomes uniform. The coverage area of the cellular link is therefore significantly extended by 343%. In addition the experimental results for a single cell system are also presented.**

***Keywords*- Visible light communication, LED, Optical Power distribution, light shaping diffuser**

I. INTRODUCTION

In the last decades, solid-state light emitting diodes (LEDs) have been widely used in color displays, traffic signals, and illumination applications. Moreover, LEDs can also be used for high speed data communications due to the fast dynamic response in the order of a few megahertz [1-3]. With the availability of highly efficient white LEDs, created by combing the prime colours (red, green, and blue) or used a blue emitter in combination with a phosphor, the dual application of illumination and data communications can be obtained [4, 5].

There are several possible link configurations for indoor optical wireless communication (OWC) system. The diffuse system which originally expounded by Gfeller and Bapst [6], displays excellent mobility, however at the cost of lower channel bandwidth due to higher path losses and the multipath induced intersymbol interference (ISI). Another scheme employs the direct line of sight (LOS), where the beam is confined within a narrow field of view (FOV). This approach offers a much wider channel bandwidth [7]. However, LOS links have limitation on the coverage area and require alignment or tracking systems to maintain the link availability. Alternatively, non-directed LOS links can be used offering both mobility and higher data rates. In this work, a diffused cellular system is proposed.

In cellular systems, there should in principle be minimum overlapping between coverage areas to achieve the optimum power efficiency. There are a number of cell shapes that could be adopted such as: circular, square, equilateral triangle, and the hexagon. For a given distance between the center of a polygon and its farthest points, the hexagon has the largest area of the three [8] with no un-covered regions between cells. In this paper, we have adopted the hexagon shape to ensure uniform distribution of the optical radiation.

The rest of the paper is organized as follow. In section II, the characteristics of transmitter, diffuser, channel model and receiver are described. In section III, the experiment work is outlined followed by results and discussion. Finally, the conclusion and future work are given in the last section IV.

II. SYSTEM DESCRIPTION

A. System Overview

The proposed indoor cellular VLC system is shown in Fig.1. The LEDs, used for lighting as well as communications, are mounted at the centre of the ceiling to achieve a hexagonal shape coverage area. At the receiving end a wide FOV photoreceiver mounted on to a mobile terminal ensure seamless connectivity as well as alleviating the need for using pointing and tracking systems.

Fig. 2 depicts the proposed practical cellular indoor VLC link. The metallic frame has a dimension of 1.8×1.5×1 m^3, which is divided into four cells each containing an LED, a holographic LSD and an optical receiver. The LEDs are mounted at the ceiling 1 m above the receiver at the floor level.

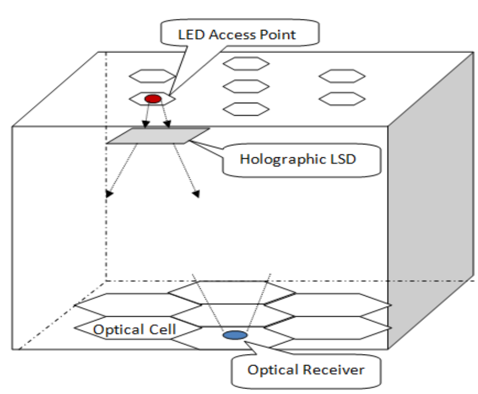

Fig. 1. Proposed indoor cellular VLC system

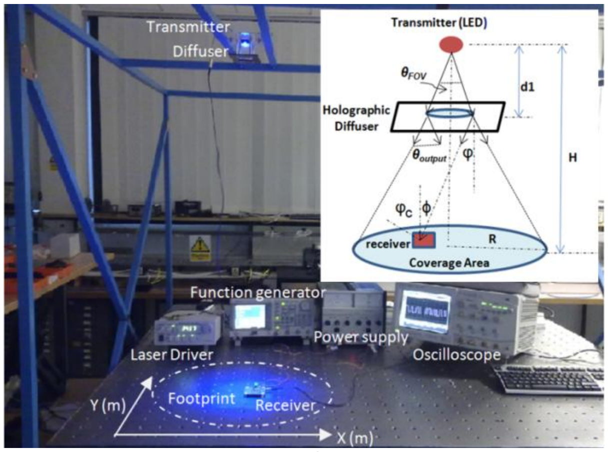

Fig. 2. Practical setup of indoor VLC system

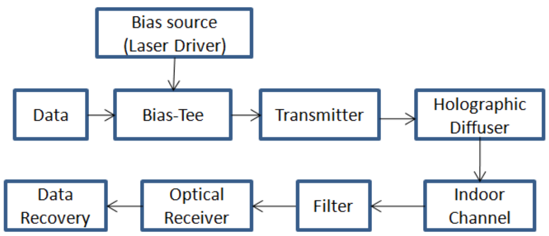

Fig. 3. A single cell VLC system diagram

B. Transmitter

Without using any beam shaping lens, the Led sources can be essentially considered as Lambertian [3]. However, in many applications there are requirements for specific radiation distributions to optimise the system performance. Here we have used LEDs with an integrated optics lens. With the transmitter having a full width at half maximum angle (FWHM) of 7^o [9], the receiving cell radius is 12.2 cm. This is equivalent to a coverage area of 474 cm^2. To achieve a wider coverage area with a uniform radiation distribution, the Luminit holographic LSD (10^0, 20^0, and 30^0) is employed. Fig. 3 shows the system block diagram of a signal cell VLC system.

C. Model of Holographic LSD

Using the holographic LSD, the effective divergence angle of the transmitter can be extended given by [6]:

(1)

where θ_{output} is the effective divergence angle of the light, θ_{FOV} is the divergence angle of light source, and θ_{LSD} is the angle of LSD [7].

The hologram is a two level surface relief diffractive element that affects only the phase of light passing through it [10]. The far-field radiation pattern passing through the hologram is approximately the Fourier transform of the surface relief structure [11]. In order to simplify the calculating of the beam intensity through the holographic LSD, see Fig. 4, we have divided LSD into an array of 'pixels'. A simulation tool is used to generate the beam profile for every 'pixel'. For each beam, the intensity of light can be considered as uniform after passing through the single 'pixel'. Finally, overall footprint of beams can be obtained by combining the multiple beam profiles.

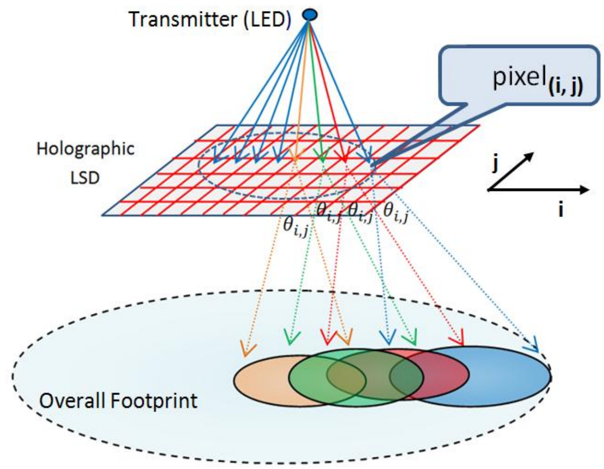

Fig. 4. Multiple beams profile after holographic LSD

D. Optical Wireless Channel

Following the LOS link configuration adopted in [12], assuming no optical filters and optical concentrators , the LOS link DC gain is given by:

(2)

where is the order of Lambertian radiant which is related to the transmitter semiangle $\varphi_{1/2}$, (at half power). The order m of the LED which we used is 110. A is the photodetector surface area, ϕ is the incidence angle, φ is irradiance angle, is the FOV (semiangle) at the receiver and H is the distance between transmitter and receiver. The received power for a single transmitter is given by:

(3)

where is the transmitted optical power of LED, is the received optical power at receiving plane.

E. Receiver

Fig. 2 illustrates the designed surface-mount receiver PCB with a size of 5 cm × 5 cm, which consists of a commercial PIN junction photodetector and a trans-impedance amplifier.

TABLE I
SPECIFICATION FOR INDOOR VLC SYSTEM

LED	Product number	LXHL-NRR8
	Bandwidth	3.8 MHz
	Wavelength	455 nm
	Output optical power	40 mW
	Field of view (FWHM)	14^o
Diffuser	Luminit LSD	10^o, 20^o and 30^0
Channel distance		1 m
Photodectector	Product number	OSD-15T
	Detection area	15 mm^2
	Responsivity	0.21 A/W (@ λ = 436 nm)
	Photodectector rise time	12 ns
Preamplifier	product number	AD8015
	3-dB bandwidth	240 MHz

III. RESULTS

The system specifications and parameters are given in Table I.

A. Simulated Results

We used Matlab to simulate the mathematical optical power distribution model of the indoor cellular OWC system. Using (2) and (3), the normalized power distribution for seven cells (see Fig. 1) is illustrated in Fig. 5. Fig. 5(a) illustrates power concentration near the centre of each cell decreasing sharply towards the cell edges. Fig. 5(b) is the contour of the power density at the receiving plane. In a 7-cell configuration with a circular footprint, the area within dotted line circles, marked in Fig. 5(b), is the 3-dB power attenuation area from the centre of a cell. The rest is defined as no coverage area or the 'dead zones' with no optical illumination. The over 3-dB coverage area (which means power attenuation is less than 3-dB in this area) for 7 cells is around 4900cm^2 which is given by:

(4)

The total area of receiving plane is given by:

(5)

where, is the 'dead zones' area, and is the overlapping area.

To achieve a uniform distribution within each cell, we have used a 30^o LSD. Figs. 6 (a) and (b) display predicted power distribution and the power density contours for a 7-cell structure. The over 3-dB coverage area is marked in Fig. 6(b). The coverage area with the 3 dB variation of intensity is around 16800 cm^2. Comparing with the a 7-cell model without diffusers, the over 3-dB coverage area is increased by 343%.

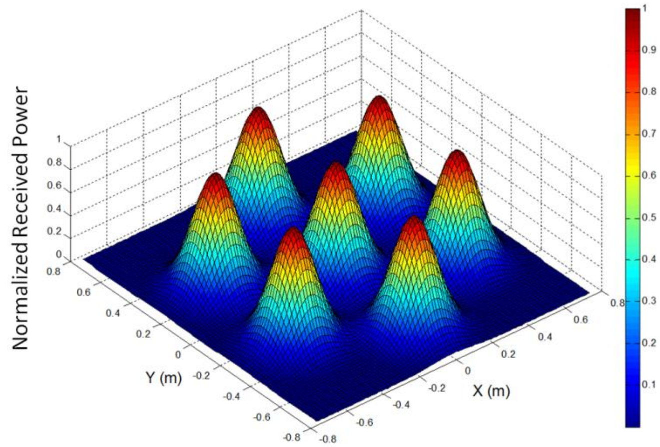

Fig. 5 (a). Predicted normalized power distribution at the receiving plane without LSD

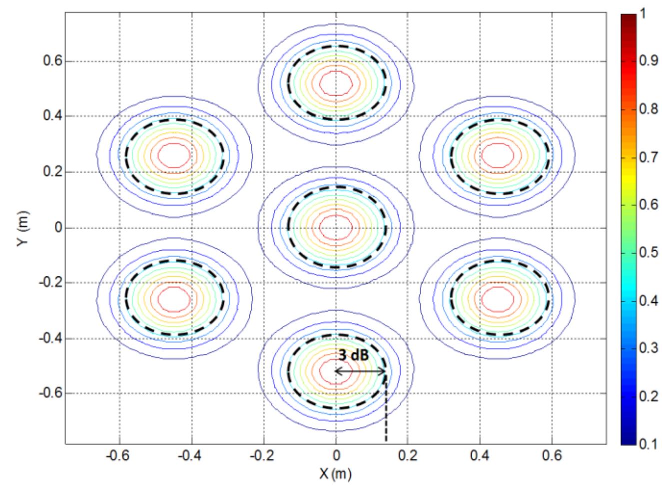

Fig. 5 (b). Predicted power contours at the receiving plane without LSD

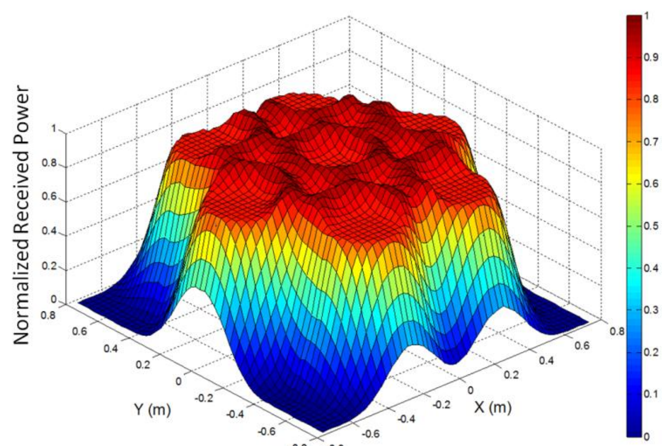

Fig. 6(a). Predicted normalized power distribution at the receiving plane using 30^o LSD

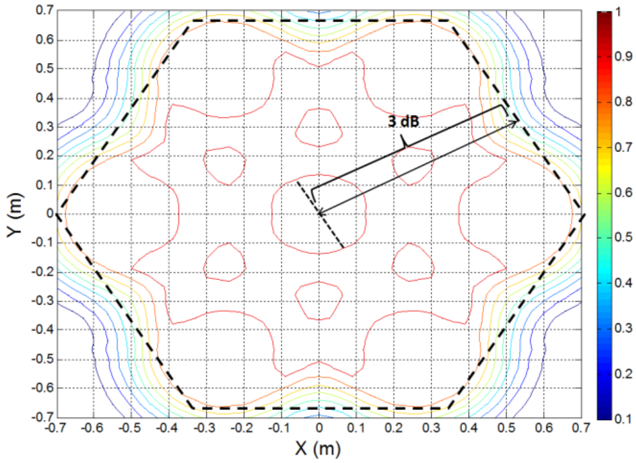

Fig. 6 (b). Predicted power contour plot at the receiving plane using 30^o LSD

B. Practical Measurements

Fig. 7 outlines the measured optical power distribution with and without holographic LSDs for a 1-cell link. With LSDs, the power density becomes more uniform when larger angles LSDs are used. Comparing the power density profiles of a link with no holographic LSD with a 30^o holographic LSD (Figs. 7(a) and (d)), it can be seen that a 3-dB transmission boundary has increased from 8 cm to 20 cm (i.e. 625% increasing in the coverage area).

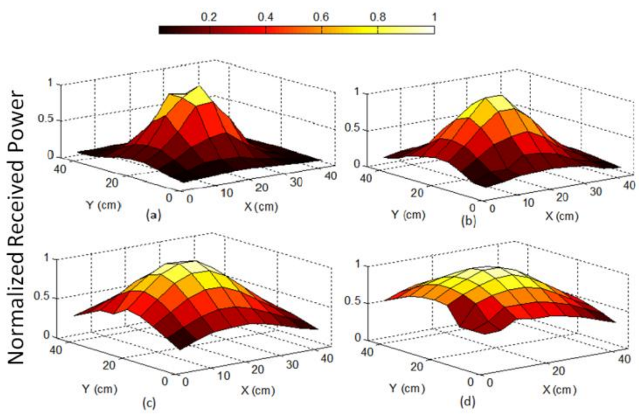

Fig. 7. Spatial distribution of received power a) without LSD, (b) with 10^o LSD, (c) with 20^o LSD, and (d) with 30^o LSD

IV. Conclusion

In this paper, we modeled, simulated and measured the received power distribution for a practical indoor VLC link employing a holographic diffuser. The investigation showed that, using holographic LSD with an appropriate angle, a uniform power distribution can be obtained and thus increase the coverage area in the indoor VLC environment. This is a step forward to design a VLC cellular system.

Acknowledgment

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